DOCUMENT RESUME

ED 441 690 SE 063 664

AUTHOR Chien, Cheng-Chih
TITLE Converting Equations and Graphs into Real Motion with Web-Based Interactive Activities.
PUB DATE 2000-04-29
NOTE 10p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (New Orleans, LA, April 28-May 1, 2000). Author's name on title page and inside the report varies.
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE EDRS Price MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Computer Uses in Education; Educational Technology; Elementary Secondary Education; *Equations (Mathematics); *Graphs; Mathematics Activities; *Physics; Science Instruction; Symbols (Mathematics); Teaching Methods; *World Wide Web
IDENTIFIERS *Representations (Mathematics)

ABSTRACT

The physics learning problem that students usually regard equations and other symbols in physics as algebraic exercises rather than representations of real world phenomena is commonly known. This article discusses how the Web-based interactive instructional materials were used to help students connect the symbolic world and the real world. The instructional design model and two examples of the learning activities are described. Implication type (large class discussion vs. small group learning), numerical problem solving ability, prior physics ability, and prior mathematics ability were analyzed while investigating student achievement in understanding the symbolic representations. The results show that students who scored higher on the symbolic understanding test also had higher scores on the numerical problem solving test. No significant differences were found on the symbolic understanding test for students with different prior physics and mathematics abilities as well as for students who received different implementation types. The reasons for these findings are discussed at the end of this article. (Author/ASK)

Reproductions supplied by EDRS are the best that can be made
from the original document.

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY
C. Chein
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

2A

Converting Equations and Graphs into Real Motion with Web-Based Interactive Activities

Cheng-Chih Chein
Tamkang University, Taiwan
Email: cchien@mail.tku.edu.tw

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.
Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

2000 NARST Annual Meeting, New Orleans, LA. April 28 – May 1, 2000

ED 441 690

Abstract

The physics learning problem that students usually regard equations and other symbols in physics as algebraic exercises rather than representations of real world phenomena is commonly known. This article discusses how the web-based interactive instructional materials are used to help students connect the symbolic world and the real world. The instructional design model and two examples of the learning activities are described. Implication type (large class discussion vs. small group learning), numerical problem solving ability, prior physics ability, and prior mathematics ability were analyzed while investigating student achievement in understanding the symbolic representations. The result shows that students scored higher in symbolic understanding test also have higher scores in the numerical problems solving test. No significant differences were found in the symbolic understanding test for students with different prior physics and mathematics abilities as well as students received different implementation types. The reasons of these findings were discussed at the end of this article.

Introduction

Kinematics is the beginning part of mechanics to introduce how symbols are used by scientists to describe motion. The commonly seen exercises found in textbooks are like: "Given $x = t^2 - 4t + 3$. When $t = 5$, what is x?" In a calculus based physics course, students can also derive the velocity and acceleration from this equation. However, if the question is: "Now that the above equation is called an equation of motion and represents the motion of an object, can you describe qualitatively how this object actually moves?" Even those who have finished the kinematics course might not be able to answer this type of questions. After students have learned the symbols (including the equations and kinematic graphs) which represent the motions do not understand what the corresponding motions are, this could be a problem in student learning.

On the other hand, World Wide Web is a very convenient medium to deliver

BEST COPY AVAILABLE

information. When this medium is selected for educational uses, it is expected to disseminate the learning materials as widely as possible. However, dissemination is not only about the medium but also the contents and activities. Are the materials posted on the web help students solve their learning problems? Can these web-based materials be used with various learning strategies as needed? Do the activities produce stable learning outcomes for teacher use as classroom materials and for student self-learning materials?

Learning Problems in Kinematics Courses

In the preliminary study, the questions about relating the symbolic representations to the real motion were given to some college freshman physics students, as well as senior physics majors, physics graduate students, and high school teachers. Most of them did not even have a clue how this type of questions can be answered. However, after the answers were given to the physics students and high school teachers, they all agreed that the question is not difficult and even high school students have learned all the needed skills to answer the question. The only problem is: "Questions were never asked this way before."

The above finding reveals two problems. The first problem is related to the content itself. Scientists observe real world phenomena and use mathematical symbols to efficiently describe their findings. When these symbols were used in schools to introduce the world to students, these symbols have no connections to the real phenomena for students. The "equation of motion" to students is an exercise of algebra rather than an equation which describes the motion. The preliminary result also indicates a problem in student learning style in physics course as well. The reason why students' existing concepts are very difficult to change may partly relate to the success of naïve concepts in limited experiences (McCloskey, Caramazza, & Green, 1980). For the same reason, if students use the plug-and-chuck strategy and always succeed in the kinematics class, they will believe this is the right way to learn science and tend to use the same strategy in mechanics, electricity and magnetism, optics, and so forth. Therefore, at the beginning of physics course it is very important to help students realize that any symbols (equations, motion diagrams, and kinematic graphs) are representations of real world phenomena.

Instructional Design

The learning activities are designed based on the Chain Model for technology-based instructional design (see Figure 1.). This model is more appropriately considered as a thinking process based on the content nature to design technology-based materials, rather than a model for instructional designers to fill in the contents into technology. Four fundamental questions are to be addressed in this model. First, what are the special

features of the topic and the associated learning problems in the content area? Second, what are the appropriate learning strategies that can be used to help students solve these problems? Third, how technologies can be used to illustrate the contents? Last, how technologies are engaged in the learning activities to facilitate the selected learning strategies?

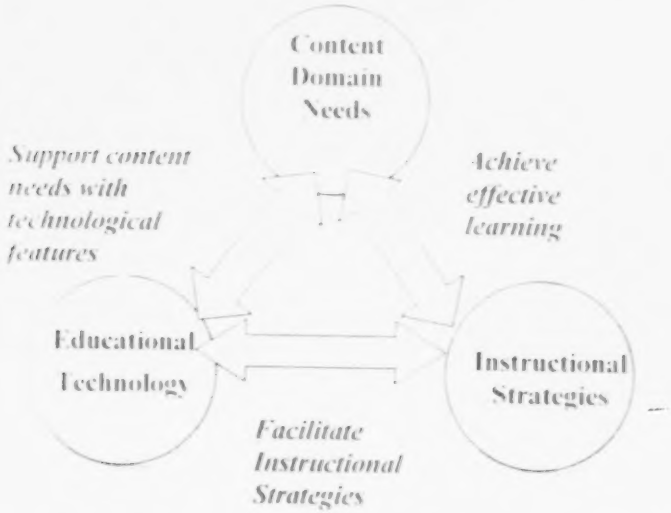

Figure 1 Chain Model for technology-based instructional material design.

In this model, the first question is regarding the special features of the topic and the associated student learning problems. Kinematics is about the description of motion. It is difficult to illustrate the real moving process with printed materials, at best with a few static pictures to show different status at various times. For students, as briefly described above, they are unable to relate the symbols (equations of motion and kinematic graphs) to the real world phenomena (the real moving process). The second question in the Chain Model is what strategies can be adopted in the learning activities to help students overcome the learning problems. To help students understand the relationship between the equation and the real motion, teachers will first demonstrate how to analyze the coefficients in the equation to visualize the motion. However, from the constructivist perspective, it is the teacher, not the students, who actually build the connection between the equation and the motion in the activity described above. To help students build this connection, it is important for them to go through the same analyzing process to find the motion after teacher's demonstration, and allow students use the fundamental knowledge learned in class to predict and evaluate how a factor changed in a symbol system would affect the motion

BEST COPY AVAILABLE

and vice versa.

So far the technology has not been discussed yet in the first two questions in the Chain Model. However, the content and strategy needs are the main factors to determine how technologies should be used in the learning activity design. The third question is how technology can be used to better illustrate the content. The learning goal of kinematics is to introduce how motion is described in various forms. The symbol systems used in printed materials are representations of motion rather than the actually moving objects. Computers are capable of converting one symbol system into another (Dickson, 1985). With computers, the real motion corresponding to a representation can be demonstrated to students simultaneously.

The converting capability not only demonstrate the symbols and real motion simultaneously, but also help engage students in leaning activities to facilitate the desired strategy for our last question in the Chain Model. When a factor is changed in one symbol system, such as a coefficient in an equation, the corresponding changes in other symbol systems, such as the motion and the kinematic graphs, will be calculated and demonstrated instantly. This symbol converting capability allows the instructional designer to implement the learning activities in which students predict, explain, and evaluate the relationship among different representations. More details will be given in the next section.

Analysis of Learning Activities

In the previous section, it is mentioned that when students were asked to describe qualitatively the motion of a car noted as $x = t^2 - 4t + 3$, most students did not have a clue about how to answer this kind of question. Why after finishing the entire kinematics unit students are still unable to describe the corresponding motion of an equation? Is it a difficult question? Some clues may be found from how they learn kinematics.

As mentioned before, a very common question in kinematics is like "when $t = 5$, what is x?" The application of this type of questions may include a car, a traffic light, a given distance, or acceleration and so forth to find the unknown in the equation. When students are asked to visualize the motion corresponding to an equation without using a calculator or pencil and paper, from their previous exercises, the following steps may come up to their mind: (1) Mentally calculate x at various time (for example, every 0.2s); (2) Remember all these x values (maybe 30 or 50 of them) and place them all on the x-axis according to time. Thus the motion can be visualized. If students are further asked to visualize the x-t graph from the equation without a calculator, they will then memorize all these values and place them all on the x-t graph. The above steps are basically what computers do to display the

motion or x-t graph. If students were expected to answer the question by the steps described above, it would not be a surprise that most students are unable to answer except some geniuses in mathematics.

However, the reasoning ability of humans makes this type of question very simple. As most students know in every kinematics lecture, the coefficients in the equation of motion represent the initial position, initial velocity, and acceleration. For example, the initial velocity and acceleration of $x = t^2 - 4t + 3$ are -4 and 2. That is, the velocity of the car initially was –4, then –2, 0, 2, 4,.... In our everyday language, the car initially moves toward the left (if left is defined as negative), slows down gradually, stops, turns back to the right, and moves faster and faster to the right. It does not take mathematics geniuses to visualize the real motion from such a simple equation. A similar technique can be used to visualize the x-t graph as well. This is what we called "qualitative understanding." This is not just a capability, but also a habit to see the implied meanings in mathematical symbols. If students believe that plug-and chuck is a successful strategy when they begin to learn physics, they will try to use the same strategy in mechanics, electricity and magnetism, optics, and so forth, rather than to understand the meanings in these laws and principles. This also explains why students totally forgot the Newton's second law **F** = m**a** when asked to predict qualitatively the force and acceleration at various location in the pendulum problem without any given numbers. (Chien, 1998)

The web-based kinematics learning module is designed to use after the lecture where students learn the fundamental knowledge about velocity, acceleration, kinematics graphs, and so forth. The learning activities are composed of two parts. The first part introduces the meanings of equations, motion diagrams, and kinematic graphs and how these symbols correspond to the real motion. The second part explores the relations between each pair of the three symbol systems.

Guided Discovery Learning

As mentioned above, the web-based materials are used after the lecture where the basic terminologies are introduced. The general format of the activities is to give students a series of questions and then students analyze the answers of these sub-questions to find the final answer. A very important feature of the web-based materials is the easy access so that students can learn anytime anywhere. Simply presenting simulations or allowing students to change the numbers to see what happens does not necessarily engage students in thinking. Or a novice student might not realize the meaning in physics when observing some changes in a simulation. It is very important for teachers to lead students to analyze the meaning of these different outputs. For example, give students an equation $x = \square t^2 +$

□t + □ and allow students to input different numbers in the empty boxes to see the corresponding motion. It might be clear for those teachers who already know the relation between the equation and real motion how the coefficients would change the motion. However, it would be too optimistic to expect most students discover the relationship after trying a few sets of numbers. Therefore, some guides accompanying with the simulations are necessary to help students to go through the analyzing process. The following example shows how students are guided from exploring the fundamental meaning to constructing a higher cognition level in kinematics.

In unit 1, "Equation and Motion," a simulation showing a car moving toward a wall is demonstrated to students. Students are also given the general information including the distance between the car and the wall, the magnitude of the initial velocity, and the magnitude of the acceleration. Then specific information about the origin and positive direction are given in different cases.

Figure 2. A car moving toward the wall with given initial speed and acceleration but no specified coordinate system.

In the first case, the origin is located at the position of the wall and the sign of the car's position is positive. Students are given the following four questions: (i) Draw the coordinate axis and indicate the positions of the wall and the car. (ii) According to the drawing, write down the initial position $\mathbf{x_o}$ (including the sign) of the car. (iii) Determine the sign of the initial velocity and write down $\mathbf{v_o}$. (iv) Determine the sign of the acceleration and write down the acceleration **a**. With the signs and magnitudes of x_o, v_o, and a, students can easily write down the equation of motion of this moving car. This is the first case and the exercise is not over yet. For the second and third cases, students are given the same moving car but with different origins and positive directions, and continue the same four steps as described above. After finish the three different cases, students will notice that even the motion is the same, the equations of motion can be different with different origins and positive directions. The reason why the same motion appears in different equations is not explained to students. Instead, the instructor directs students to review the guided questions and has students discuss why these equations are different.

A similar but reverse process is also given to students to reinforce the idea: Given an equation, such as $x = t^2 - 2t + 3$, what are the corresponding motion? With this equation, we know this is a one-dimensional motion, initial position 3, initial velocity toward

negative direction, and the acceleration is positive. That is, the object starts moving in one direction and then slowing down, stopping, and moving back to the opposite direction. From the description, we can create several situations such as: "a car moving toward left and going back toward right", or "a ball rolling up and down on an incline", or "a stone being thrown up in the air in a planet in the space." Since the same motion can be described by different equations and the same equation might also represent different motions, the instructor can now lead the students to discuss why they have to "read" the equations rather than to "memorize" the equations. After finishing these activities, students are expected not only to know how the coefficients in an equation would change the motion, but also to realize a more general characteristic of general relationship between symbol systems and real world phenomena. Similar activities are also in the motion diagram and kinematic graph units to help students relate these symbols to real motion.

Knowledge Construction and Reconciliation

After students realize the meaning of each individual symbol, students explore the relationship among different symbol systems. In unit 4, "Equation vs. Motion Diagram," a moving ball with a velocity arrow is shown on the screen (see Figure 3). Next to the ball is a car controlled by the equation of motion. Students are to manipulate the coefficients of the equation so that the ball and the car have the identical motion. To match the motion, students have to determine the signs of the initial velocity and the acceleration according to the motion of the ball first. Then students randomly guess the magnitudes of the coefficients and run the simulation to compare the motion of the two objects. From the result of the simulation, students have to determine how these coefficients should be modified so that the motion could match better until the two motions are identical. After going through a series of modification and evaluation process, students get better idea on the relationship between the equation and the motion diagram. In unit 5 and 6, students also learn to predict kinematic graphs with given motion diagrams and predict the equations with given kinematic graphs, and vice versa.

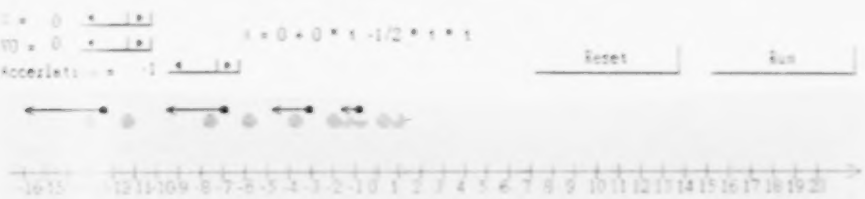

Figure 3. A simulation allows students to manipulate the coefficients of the car to match the motion of the ball.

BEST COPY AVAILABLE

Research Design

The subjects are the freshman students in physics department. The learning outcomes are compared between two treatment groups. In one group, the classroom was equipped with one computer and an overhead projector. The web-based activities were used by the instructor in the form of lecture and group discussion in the recitation class. In the other recitation class, three students worked together on one computer in a computer laboratory. Printed handouts with guided questions were given to students. The instructor did not lecture nor conduct the discussion, but only helped students when needed. In addition to the types of implementation of the web-based activities, student performance in the traditional end-of-chapter type problems in the midterm examination, physics and mathematics scores in the college entrance examination are the factors that might affect student achievements in understanding symbols. The preliminary study shows that most students were unable to answer how symbols are related to real motion even after the class. This result, in fact, imposes some difficulties to conduct a research studying student performance with without the treatment. If the test is given in an examination of which the scores will be counted as part of the overall grades, students who did not receive the treatment might be very panic during the test. Later they will notice that this type of questions was explicitly given in the other recitation class. This will cause some problems for the physics department. For a test of which the scores are not to be counted, usually questions testing student intuitions and in the form of multiple choices (such as the Force Concept Inventory) are more appropriate. Due to the nature of extensive thinking activity and some writing and graphing involved in the test, some students might simply not answer these questions if they were informed that the test would not be graded. Therefore, only four factors (implementation type, prior physics ability, prior mathematics ability, and quantitative problem solving ability in kinematics) were considered in studying student ability in relating the symbolic representations to the real world motion as well as converting one symbol system into another.

Finding and Discussion

A four-way ANOVA was used to determine the relationship of the four factors (implementation type, quantitative problem solving ability, prior physics ability, and prior mathematics ability) to student achievement in understanding the symbolic representations. The total score of the representation understanding test is 20 points. A significant difference ($F(1,78) = 7.40$, $p < .008$) is found between students who scored higher in the numerical problem solving ability ($M = 15.69$) than students who scored lower ($M = 13.20$). The result might suggest that better understanding on the meanings of the equations, motion

diagrams, and kinematic graph would help students in numerical problem solving as well.

Other findings include that there is no significant difference ($F(1,78) = 1.089$, $p < .300$) found whether the web-based activities were demonstrated by the instructor ($M = 13.99$) or used by students in small groups ($M = 14.90$). Because the learning module provides a series of guided questions for each problem, the instructor or the students can easily follow the thinking steps so that a relatively stable result can be found with different types of learning. This is an important feature for web-based materials where students sometimes work by themselves at their convenient time and place.

Some activities in the module seem to depend heavily on the mathematical ability. For example, students are expected to visualize the motion with a given mathematical equation. The analysis shows that student prior mathematics ability is not an important factor in predicting student ability to convert different symbol systems ($F = 19.60$, $p < .221$). In fact, as discussed before, the key to visualize the motion from an equation is to figure out the information of initial position, initial velocity, and acceleration from the equation and how acceleration would change velocity. It takes relatively less mathematical skills but more conceptual understanding on the coefficients in the equation.

The analysis also shows that there is little relationship between student prior physics ability and the desired ability ($F = .55$, $p < .816$). As discussed in the preliminary test, most students are unable to relate symbols used in the kinematics to the real motion after finishing physics courses. Although converting the symbols into motion is not difficult for students, the relation between the symbols and the real phenomena are not usually discussed in most physics courses. This might explain why student high school physics ability does not make a significant difference on the converting ability in the college introductory physics course.

Reference

Chien, C. (1998, April). The effectiveness of interactive computer simulations on learning circular motion. Paper presented at the meeting of the National Association for Research in Science Teaching, San Diego, CA.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: Naive beliefs about the motion of objects. Science, 210, 1139-1141.